Commercial feasibility of integrated gasification combined cycle (IGCC)

Francisco García Peña – ELCOGAS Puertollano IGCC plant
1. The ELCOGAS plant

1.1 Introduction

1.2 Description of the IGCC process

1.3 Operational data

1.4 CO$_2$ separation and H$_2$ production

2. Lessons learnt

2.1 What is gasification?

2.2 Engineering plant modifications

2.3 “Demonstration project”

2.4 CO$_2$ capture experience
ELCOGAS is an Spanish company established in April 1992 to undertake the planning, construction, management and operation of a 335 MWe ISO IGCC plant located in Puertollano (Spain)

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Pet coke</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (%w)</td>
<td>36.3</td>
<td>82.2</td>
</tr>
<tr>
<td>Ash (%w)</td>
<td>41.1</td>
<td>0.3</td>
</tr>
<tr>
<td>S (%w)</td>
<td>0.9</td>
<td>5.5</td>
</tr>
<tr>
<td>LHV (MJ/kg)</td>
<td>13.1</td>
<td>32.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Gross</th>
<th>Net</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Output</td>
<td>317.7 MW</td>
<td>282.7 MW</td>
</tr>
<tr>
<td>Efficiency (LHV)</td>
<td>47.1 %</td>
<td>42.2 %</td>
</tr>
</tbody>
</table>
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Description of the IGCC process

- **Coal preparation**
  - Coal
  - Limestone
  - Petroleum Coke

- **Gasifier**
  - Raw Gas
  - Hot Combustion Gas
  - Quench Gas
  - Slag
  - Fly Ash

- **Filtration**
  - Water Wash
  - Water to Treatment
  - Air

- **Water Wash**
  - Tail Gas
  - Claus Gas

- **Sulfur Recovery**
  - Sulfur (99.8%)

- **Air Separation Unit**
  - Compressed Air
  - Waste N₂

- **Steam Turbine**
  - 135 MW ISO

- **GAS Turbine**
  - 200 MW ISO

- **Heat Recovery Steam Generator**
  - Flue Gas to Stack
  - Steam
  - MP Steam

- **Condenser**
  - Cooling Tower

**Coal - N₂**

**O₂**
Description of the IGCC process

**Fuel design values**

Fuel design is a mixture 50/50 of coal/coke which now is 45/55. Moreover some tests with biomass were undertaken (meat bone meal, grape seed meal, olive oil waste).

<table>
<thead>
<tr>
<th></th>
<th>COAL</th>
<th>PET COKE</th>
<th>FUEL MIX (50:50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%w)</td>
<td>11.8</td>
<td>7.00</td>
<td>9.40</td>
</tr>
<tr>
<td>Ash (%w)</td>
<td>41.10</td>
<td>0.26</td>
<td>20.6%</td>
</tr>
<tr>
<td>C (%w)</td>
<td>36.27</td>
<td>82.21</td>
<td>59.21</td>
</tr>
<tr>
<td>H (%w)</td>
<td>2.48</td>
<td>3.11</td>
<td>2.80</td>
</tr>
<tr>
<td>N (%w)</td>
<td>0.81</td>
<td>1.90</td>
<td>1.36</td>
</tr>
<tr>
<td>O (%w)</td>
<td>6.62</td>
<td>0.02</td>
<td>3.32</td>
</tr>
<tr>
<td>S (%w)</td>
<td>0.93</td>
<td>5.50</td>
<td>3.21</td>
</tr>
<tr>
<td>LHV (MJ/kg)</td>
<td>13.10</td>
<td>31.99</td>
<td>22.55</td>
</tr>
</tbody>
</table>

**Syngas composition**

<table>
<thead>
<tr>
<th></th>
<th>RAW GAS</th>
<th>CLEAN GAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Real average</td>
<td>Design</td>
</tr>
<tr>
<td>CO (%)</td>
<td>59.26</td>
<td>61.25</td>
</tr>
<tr>
<td>H₂ (%)</td>
<td>21.44</td>
<td>22.33</td>
</tr>
<tr>
<td>CO₂ (%)</td>
<td>2.84</td>
<td>3.70</td>
</tr>
<tr>
<td>N₂ (%)</td>
<td>13.32</td>
<td>10.50</td>
</tr>
<tr>
<td>Ar (%)</td>
<td>0.90</td>
<td>1.02</td>
</tr>
<tr>
<td>H₂S (%)</td>
<td>0.81</td>
<td>1.01</td>
</tr>
<tr>
<td>COS (%)</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td>HCN (ppmv)</td>
<td>23</td>
<td>38</td>
</tr>
</tbody>
</table>
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   2.4 CO$_2$ capture experience
1st 5 years: Learning curve

2003: Major overhaul Gas Turbine findings

2004 & 2005: Gas turbine main generation transformer isolation fault

2006: Gas turbine major overhaul & candle fly ash filters crisis

2007 & 2008: ASU WN2 compressor coupling fault and repair MAN TURBO

2010: No operation due to non-profitable electricity price (30-40 days).

2011: 100,000 EOH Major Overhaul

2012: **1,498 hours in stand-by due to regulatory restrictions**
ELCOGAS power plant emissions in NGCC & IGCC modes
### Operational data: Variable Cost

<table>
<thead>
<tr>
<th>Fuel mode</th>
<th>Fuel</th>
<th>Consume (GJPCS)</th>
<th>Production (GWh)</th>
<th>Heat rate (GJPCS/GWh)</th>
<th>Fuel cost (€/GJPCS)</th>
<th>Partial cost (€/MWh)</th>
<th>Total cost (€/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GT</strong></td>
<td>Natural gas</td>
<td>59,987</td>
<td>2.891</td>
<td>20,748</td>
<td>10.46</td>
<td>216.98</td>
<td>216.98</td>
</tr>
<tr>
<td><strong>NGCC</strong></td>
<td>Natural gas</td>
<td>249,495</td>
<td>22.154</td>
<td>11,262</td>
<td>10.46</td>
<td>117.77</td>
<td>117.77</td>
</tr>
<tr>
<td><strong>NGCC + ASU</strong></td>
<td>Natural gas</td>
<td>1,854,675</td>
<td>155.148</td>
<td>11,954</td>
<td>10.46</td>
<td>125.01</td>
<td>125.01</td>
</tr>
<tr>
<td><strong>NGCC+ASU+Gasifier (by flare)</strong></td>
<td>Natural gas</td>
<td>351,147</td>
<td>33.373</td>
<td>10,522</td>
<td>10.46</td>
<td>110.03</td>
<td>128.69</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
<td>67,459</td>
<td></td>
<td>2,021</td>
<td>3.49</td>
<td>7.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petocke</td>
<td>195,947</td>
<td></td>
<td>5,871</td>
<td>1.98</td>
<td>11.61</td>
<td></td>
</tr>
<tr>
<td><strong>IGCC</strong></td>
<td>NG auxiliar</td>
<td>257,700</td>
<td>992.811</td>
<td>260</td>
<td>10.46</td>
<td>2.71</td>
<td>26.30</td>
</tr>
<tr>
<td></td>
<td>Coal</td>
<td>2,536,891</td>
<td></td>
<td>2,555</td>
<td>3.49</td>
<td>8.91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Petocke</td>
<td>7,368,734</td>
<td></td>
<td>7,422</td>
<td>1.98</td>
<td>14.67</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Net energy variable costs (average 2012)
Unavailability in 4 years maintenance cycle (2009 – 2012)

Technology at demonstration state

- First four large coal-based plants (USA & EU, 1994 - 1998) show 60-80% of IGCC availability (> 90% considering auxiliary fuel)
- Main unavailability causes related with its maturity lack:
  - Auxiliary system design: solid handling, downtime corrosion, ceramic filters, materials and procedures
  - Performance of last generation turbines with syngas or natural gas
  - Excessive integration between units. High dependence and start-up delay
  - More complex process compared to other coal-based plants. Learning is necessary. IGCC power plants using petroleum wastes show higher availability than 92%
Operational data: Costs

ACCUMULATED INVESTMENT COSTS:

- Fuel handling plant
- Cooling system
- Control system
- A.S.U
- B.O.P.
- Combined Cycle
- Gasification

Million Eur


REPRESENTATIVE YEAR (2008) OPERATING COSTS,
WITHOUT FINANCIAL COSTS: Total: 83.602 K€ (57.90 €/MWh)

- Fixed costs:
  - Total: 29.441 K€ (20.39 €/MWh)

- Variable costs:
  - Fuels: 54.276 K€ (37.59 €/MWh)
Cost Of Electricity €/MWh

TOTAL COE Euros 2012

- COE Financials
- COE Variable
- COE Fixed O&M


€/MWh
Benefit or lost before taxes, is directly related to the regulatory framework of each time.

Operational data: Economic results

Σ Losts 110,7 milions €
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**CO₂ separation and H₂ production**

**COAL + COKE**

- Gasification

**Filtration System**

- Raw gas

**Purification & Desulphuration**

- Syngas

**Combined Cycle**

- Tail gas 1,3 bar

**CO₂ Separation and H₂ Production**

- Chemical, aMDEA

<table>
<thead>
<tr>
<th>Flow (Nm³/h)</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,610</td>
<td>4,006</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>P (bar)</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.8</td>
<td>23.6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>126</td>
<td>138</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% CO₂</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.45</td>
<td>53.72</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>% H₂</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.95</td>
<td>19.57</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% H₂O</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.29</td>
<td>10.40</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% H₂S</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.70</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% COS</th>
<th>SWEET</th>
<th>SOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.11</td>
<td></td>
</tr>
</tbody>
</table>

**H₂ Rich Gas**

- 37.5% CO₂
- 50.0% H₂
- 3.0% CO

**IP Steam**

- Shift Reactor SWEET/SOUR

- CO + H₂O → CO₂ + H₂

**CO₂ & H₂ Purification (PSA)**

- Raw H₂ (80% of purity)
- 40%
- Tail gas 1.3 bar
- Pure H₂ (2 t/d)
- 99.99% H₂ @ 15 bar

**CO₂ + H₂S (1.44%)**

- 100 t/d
CO₂ capture & H₂ production pilot plant
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Gasification itself is not the core neither the root of the project nor plant problematic. It is the design, detailed design, of the auxiliary systems. Each plant is different because they depend on:

- Available raw fuel
- Chosen gasifier technology
- Expected use of syngas
- Environmental regulations

**So Engineering & O&M expertise are crucial**

**Syngas production by gasification. Processes**

- **Feeding**
  - Dry
  - Wet

- **Gasification**
  - Fixed bed
  - Fluid bed
  - Entrained bed

- **Cooling**
  - Heat exchangers
  - Direct with water
  - Chemical

- **Particles separation**
  - Dry filtration
  - Wet filtration

- **Scrubbing**
  - One step
  - Two steps

**Desulphurization**
- COS hydrolyzation
- Chemical absorption
- Physical absorption
- Adsorption

**Clean syngas**
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Engineering plant modifications

ANNUAL EVOLUTION OF APPROVED DESIGN CHANGES

Commissioning of BOP & CCNG
Commissioning of ASU & Gasification and CCwSG
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"DEMONSTRATION PROJECT"

Investment costs at ELCOGAS. Learning

REGULATORY SUPPORT is essential in technology demonstration project at commercial scale

Total production cost
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Real experience at ELCOGAS: Pilot plant

Comparison between costs of CO₂ capture technologies

With acid CO₂ capture & current status of technology

~125

~25

30 for ELCOGAS retrofitting

Source: DOE/NETL CCS RD&D ROADMAP (December 2010)
Real experience at ELCOGAS: results and learning

**CO₂ capture in IGCC**

- **With SWEET catalyzer**
  - Fuel preparation → Gasification → Filtration and wet scrubbing → Desulphurization and sulphur recovery → Unity of CO₂ capture → Combined cycle

- **With SOUR catalyzer**
  - Fuel preparation → Gasification → Filtration and wet scrubbing → Unity of CO₂ capture → Combined cycle

Based on our CO₂ capture pilot plant, we have scaled the cost of a CO₂ capture unit at scale 1:1 about 350 M€. Approximately that is the cost of the desulphurization and sulphur recovery unit in an IGCC w/o CO₂ capture.

By installing an IGCC with CO₂ acid capture to store or use CO₂ together with ~1.5% H₂S, the investment costs are similar w/o CO₂ capture. And the only penalty is the decreasing efficiency: From 42% currently and from 50% near future.
TECHNOLOGY DEMONSTRATION POWER PLANT AT COMMERCIAL SCALE REQUIRES A LONG TERM REGULATORY FRAME

IGCC WITH OR WITHOUT CCS IS A PROMISING TECHNOLOGY WITH MINIMUM VARIABLE COSTS AND BEST ENVIRONMENTAL PERFORMANCE

FOLLOWING GENERATION MUST LEARN FROM EXISTING PLANTS

MAIN BURDEN FOR DEPLOYMENT: HIGH INVESTMENT REQUIRES LONG TERM REGULATORY FRAME